STABILIZE MACHINING CONDITION OF ELECTRICAL DISCHARGE MACHINING TO MINIMIZE FRICTION OF HIP IMPLANT

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To my beloved father and mother (Mahmud Man and Fatimah Jaafar)
My beloved husband, Mohd Zulhairi Daud
My beloved daughter, Nur Alyaa' Qaisarah Mohd Zulhairi
My beloved siblings (Siti Zahrah, Azizah and Maimunah)
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ABSTRACT

Electrical Discharge Machining, EDM is one of the technologies used for surface modification such as the embedded micro-dimples on the metallic acetabular cup. During the machining process, changes in the gap distance may lead to load changes from open to short circuit. Limiting the load current under short circuit conditions and load voltage under open circuit conditions is the requirement in this system. Power supply is one of the elements that controls the process parameters which is related to improve the machining condition as well as Material Removal Rate (MRR). This research proposes a Switch Mode Power Supply method implementing new design of Flyback power supply which can stabilize the voltage during open circuit condition as well as during discharge condition. A model of Flyback power supply was designed and simulated using MATLAB/SIMULINK to investigate the response of the model by measuring the output voltage. The design was then fabricated and an experiment was conducted to validate the simulation. Eight micro-dimples in lower position and twelve micro-dimples in upper position, both in circular arrangement were machined on metallic acetabular cup using Flyback power supply and Linear power supply. Each micro-dimples were then further investigated to find the MRR. The experimental studies then followed by tribological test to screen the friction and wear rate. This experimental work is conducted using four ball tester to describe the friction from the coefficient of friction value measured. Research conducted shows that the Flyback power supply improve the consistency of MRR by 4.2 % for electrode diameter 1000 µm and 21 % for electrode diameter 500 µm. This consistency may help to predict the machining time, thus improving the production of micro-dimples in required time. The quantitative results of the friction test concluded that metallic acetabular cup with 8 micro-dimples has reduce the friction and delayed severe damage, which may then prolong the survival rate of hip implant.

ABSTRAK

Pemesinan Nyahcas Elektrik (EDM) adalah salah satu teknologi yang digunakan dalam pengubahsuaian permukaan seperti penghasilan lubang mikro di atas permukaan melengkung implan pinggul. Semasa proses penghasilan lubang mikro, perubahan jarak di antara elektrod dan bahan kerja membolehkan perubahan beban berlaku dari litar terbuka kepada litar pintas. Mengehadkan arus beban ketika keadaan litar pintas dan voltan beban ketika litar terbuka adalah keperluan dalam sistem ini. Bekalan kuasa adalah salah satu elemen yang mengawal proses tersebut bagi memperbaiki keadaan semasa pemesinan dan meningkatkan Kadar Hakisan Bahan (MRR). Kajian ini mencadangkan satu reka bentuk penjana kuasa baru dikenali sebagai bekalan kuasa *Flyback* yang boleh menstabilkan voltan semasa keadaan litar buka serta semasa keadaan nyahcas. Model *Flyback* direka dan disimulasi menggunakan MATLAB/SIMULINK untuk menyiasat tindak balas model dengan mengukur voltan keluaran. Model fizikal kemudian dilaksanakan dan kajian eksperimen dilakukan untuk mengesahkan simulasi. Lapan dan dua puluh lubang mikro pada permukaan logam melengkung dalam susunan membulat dimesin menggunakan bekalan kuasa *Flyback* dan bekalan kuasa *Linear*. Setiap lubang mikro kemudiannya dianalisa untuk mendapatkan kadar hakisan bahan. Ujikaji diteruskan dengan ujian tribologi untuk menyaring geseran dan kadar kehausan dalam logam ke logam permukaan melengkung ditentukan melalui Nilai Pekali Geseran (CoF) yang diukur. Keputusan menunjukkan bahawa konsistensi MRR adalah lebih tinggi ketika bekalan kuasa *Flyback* digunakan dengan peningkatan 4.2 % untuk elektrod diameter 1000µm dan 21 % untuk elektrod 500 µm. Konsistensi ini boleh membantu untuk meramalkan masa pemesinan, sekaligus meningkatkan pengeluaran lubang mikro dalam masa yang diperlukan. Analisa kuantitatif daripada ujikaji geseran menyimpulkan lapan lubang mikro dapat melambatkan kerosakan kepada permukaan melengkung, di mana seterusnya boleh memanjangkan hayat implan.

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LIST OF ABBREVIATIONS

BJT	-	Bipolar Junction Transistor
CoC	-	Ceramic-on-Ceramic
CoF	-	Coefficient of friction
CoP	-	Ceramic-on-Polymer
EDM	-	Electrical Discharge Machining
MoM	-	Metal-on-Metal
MoP	-	Metal-on-Plastic
MRR	-	Material Removal Rate
PO	-	Palm Olein
PRC	-	Parallel resonant converter
RC	-	Resistance-capacitance
SMPS	-	Switch Mode Power Supply
SR	-	Surface roughness
SRC	-	Series resonant converter
TWR	-	Tool Wear Rate

LIST OF SYMBOLS

W_b	-	Weight before
W_a	-	Weight after
I_p	-	Current pulse
t_{off}	-	Pulse off-time
t_{on}	-	Pulse on-time
V_p	-	Voltage pulse
α	-	Removal constant of material
L	-	Normal applied load
η	-	Lubricant viscosity

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CHAPTER 1

INTRODUCTION

1.1 Background of the Study

Hip joint is one of the most important joint in human body that help in our daily movement. It composed of a femoral stem (thigh bone) with a femoral head on top of it. The femoral head articulates against the acetabular cup in the acetabulum [1]. The femoral head and the acetabular cup are coated by a cartilage that lubricates their movement and facilitate the articulation. However, this joint may prone to degenerate due to any causes such as arthritis, damage from injury, or in aged people. As an example, in an arthritic hip joint, the cartilage has been damaged due to inflammation or by degenerative process. If only a part of the joint is damaged, the surgeon may be able to repair the damaged part. However, if the entire joint is damaged, Total Hip Arthroplasty (THA) is suggested in which the damaged part is removed and replaced by an implant [2]. Materials combination between femoral head and acetabular cup is one of the factors affecting the longevity of the hip implant. There are four broad material combinations which are metallic femoral head in a polymeric cup (MoP), ceramic head in a polymeric cup (CoP), ceramic head in a ceramic cup (CoC) and metallic head in a metallic cup (MoM). Severe wear and aseptic loosening of polymer material are the main reasons in failure of MoP and CoP hip implant. Thus, hard-on-hard materials have been introduced which is (CoC) and (MoM). Major problem with CoC implant is squeaking which found to have significant influence on wear mechanism [3]. Although many first generation of MoM failed to severe wear, the second generation exhibits encouraging wear resistance due to development in material choice, design and manufacturing. Wear rate and friction are known as the major concerns for determining the lifespan of MoM hip implant. From engineering point of view, wear and friction could be minimized through improving lubrication, thus similar principal can be applied to MoM hip implant by surface texturing technique.

Surface texturing technique was previously used on golf ball surfaces to improve their aerodynamic characteristic. Surface texturing is now employed in implant design due to the improved lubrication performance as well as reducing wear and friction. Numerical studies on surface texturing have indicated micro-texture may significantly affect the tribological performance of contact surface and improved lubrication performance [4]. However, there are few surface texture experimental studies in the metallic hip implant, especially in surface dimpling. This approach of surface texturing by applying micro-dimples on the metallic acetabular help to promote in reservation and distribution of lubricant between the contact surfaces thus give better tribological performance [5]. There are many surface texture technologies used for surface modification such as CNC micro drilling, Solid State Laser, Abrasive waterjet and Electrical Discharge Machining (EDM). Due to stamping and drilling process in conventional machining technique, the micro-dimples may suffer from micro cracks. Non-contact process which is the characteristic of EDM would be the best solution to replace drilling and stamping process. While considering the micro-dimples quality, EDM is suggested since it results in no burr formation. Since EDM process is of stochastic nature, it requires a lot of improvements on it especially while considering machining of micro-dimples on metallic acetabular cup. Most of the literatures have discussed about relating of machining parameters to improve performance measures [6], modelling and optimization of the process variables [7,8], and monitoring and control of the sparking process [9]. It has been observed that less attention has been given for enhancing electrical process parameters of EDM process in terms of controlling the process variable such as voltage and current. These two variables highly influence the EDM performance measurement such as Tool Wear Rate (TWR), Material Removal Rate (MRR), and Surface Roughness (SR). Among the three, MRR is the most dominant performance measure in this study since it affects the quality of micro-dimples in term of consistency of material removal for each micro-dimple.

MRR is defined as the volume of material removed per minutes. Material removal in EDM is realized by thermal action of electrical discharge between the tool and the workpiece, which are connected to a DC power supply. The discharge energy released by this power supply is responsible for melting small quantity of material of both electrode and workpiece. This power supply generates high enough voltage to breakdown the dielectric at a very small gap (10-50μm). Before the striking of the spark, the power supply operated at no load condition as the output sees an open circuit. The EDM servo system then adjusts the position of the electrode to breakdown the dielectric. The power supply then sees a negative resistance until the voltage drops to the working gap which is normally ranges from 10-25 V. The current is maintained during this time until the pulse is terminated. The process is repeated at the next cycle. With the working principle stated, enhancing the power supply design that meets the EDM system working principle is necessary.

The conventional power supplies applied in EDM are typically traditional Linear converter, which is act as current source. The major problems of this power supply include large volume and high power losses. In order to solve these problems, resonant-switching power converter is introduced. However, the drawback is when the load resistor of the resonant tank is in high impedance state, the output voltage of the resonant tank is fairly high. The power supply for EDM can be implemented using conventional converter topologies such as buck, buck-boost, single-ended primary-inductance converter (SEPIC) and Flyback converter. The major concern in buck-boost is it inverted polarity in the output terminal while control complexity and components counts are the disadvantages of SEPIC converter. Buck based topology is preferred for implementing the power supply [10], however due to desirable of low output power for EDM application, Flyback converter is suggested. Several studies implementing Flyback converter only discuss on the design of the power supply by evaluating the gap voltage, gap current and surface images after machining process [11–13]. Therefore, this study provides an intensive knowledge of using Flyback converter in EDM system by analyzing the gap voltage, gap current, surface images and MRR. Experimental results of using Flyback converter comparing with Linear converter are provided by machining micro-dimples on metallic acetabular cup. This novel study is to highlight the design of power supply which can stabilize the voltage during open circuit condition as well as during discharge condition which in turn ensure stable energy levels provided to the gap during machining process. Stable energy level during machining process will lead to high material removal. This power supply will be applied between the electrode and workpiece (acetabular cup) for machining micro-dimples. The machined micro-dimples are expected to improve surface quality as well as consistency of material being removed.

This research seeks to focus on the design and development of power supply utilizing Flyback converter. This approach is compared with Linear power supply by evaluating the consistency of MRR for each micro-dimples machined on metallic acetabular cup of hip implant. Since concern on surface texturing to the hip implant has been rising, this study provided a significance idea on surface texturing by embedded the acetabular cup with micro-dimples. The friction between the femoral head and micro-dimpled acetabular cup is analyzed using four ball tester. The result is compared with non-dimpled acetabular cup. This study will add knowledge to the tribological study of hip implant, as this method expected to minimize friction on hip implant.

1.2 Problem Statement

Enhancing the performance measure of EDM process such as Material Removal Rate (MRR) is widely done on several studies. There are, study on the effect of machining parameters to MRR, modelling and optimization of the process parameters during the discharge process as well as monitoring and control of the spark in order to improve the MRR. Less attention given on the development of the power supply that controls the process parameters itself. Regulation is important for the output voltage to be relatively independent of line or load variations. The regulator circuit compares the output with a reference and adjusts the current flow to make the output as nearly equal to the desired voltage as possible. However, a significant amount of power may be lost in the regulator especially under high line voltage/high load conditions. Therefore the efficiency of Linear power supplies is usually quite low. This lead to less material removal throughout the EDM process. Thus, a Switch Mode Power Supply (SMPS) has been introduced in EDM which high frequency switching devices such as Bipolar Junction Transistors (BJTs) and MOSFETs, are used to directly rectified line voltage and convert it to a pulsed waveform. Since the switching devices are fully on or fully off, there is relatively little power loss. Therefore, the efficiency can be much higher for SMPSs. Due to this advantage, SMPS is proposed that supply the power for erosion to take place. This SMPS consists of feedback which helps to stabilize the power supplied with changing load. Stabilize machining condition will lead to more consistent material removal during the EDM process. This stabilize machining condition is required to machine micro-dimples on acetabular cup of hip implant in order to promote lubrication activities that lead to minimize friction of hip implant.

1.3 Objectives

Based on the issue regarding EDM and MoM hip implant, there is a demand for researcher to develop power supply which will be used to machine micro-dimples on a model of metallic acetabular cup. Thus, this study embarks on the following objectives:

1. To design and develop Switch Mode Power Supply (SMPS) using Flyback converter tailored for machining micro-dimples on hip implant
2. To analyze the consistency of Material Removal Rate (MRR) by comparing two types of power supply namely Linear power supply and Flyback power supply.
3. To analyze friction between femoral head and acetabular cup by conducting tribology test using modified four ball machine.

1.4 Scope of Study

The following scopes of work are covered as follows:

1. A broad but critical literature review of Electrical Discharge Machining. The review covered on power supply, machining parameter and machining performance.
2. A simulation using MATLAB is conducted to predict the response of Switch Mode Power Supply before implement it into hardware.
3. The implementation of the SMPS is applied to the laboratory scaled EDM machine.
4. Machining of micro-dimples in circular arrangement with total of eight micro-dimples and twenty micro-dimples are conducted.

5. An experiment of machining process is conducted in order to measure the consistency of material removal rate for Linear power supply as well as SMPS.
6. The result of machining micro-dimples on metallic acetabular cup hip implant is then tested using modified four ball tester to observe the friction when micro-dimples are applied using different power supply.

1.5 Limitations

The limitations of this study are as follows:

1. Experiment for tribology test was limited to Palm Olein as the lubricant with load of 40N.
2. The diameter of the dimples was limited according to the electrode size of 500 µm and 1000µm.
3. Experiment for machining micro-dimples on model of hip implant was limited to metal-on-metal material bearing combinations.

1.6 Assumptions

The following assumptions are made in this study:

1. Temperature and pressure of dielectric fluid were constant during the experiment for machining micro-dimples
2. Current consumption was constant throughout the experiment for machining micro-dimples.
3. The temperature was assumed to be 37±3 °C throughout the tribology test.

1.7 Significant of study

MRR is one of the performance measures which are widely emphasized by other researchers in order to improve the capability of EDM process. The study of consistency of MRR is important as it directly affect the machining time as well as the surface quality of each micro-dimples machined on acetabular cup of hip implant. More consistent value of MRR will lead to nearly equal quality of micro-dimples produced such as depth and diameter of the micro-dimples. This help in reserving the same amount of lubricant for each micro-dimple that lead to wear and friction reduction, thus prolonging the lifespan of the hip implant. The value of MRR is essential to the selection of power supply used for machining. Therefore the study of designing power supply using switch mode technology is necessary for replacing the existing Linear converter power supply. This adds value to the surface texturing industry by using EDM with switch mode technology. This research also aims to observe the effectiveness of micro-dimples embedded in the metallic acetabular cup used for lubrication purpose. For biomedical field, this study add knowledge to the design of hip implant with textured with micro-dimples.

1.8 Organization of the thesis

Chapter 1 introduces this study including problem statement, objectives, scope, limitations, assumptions made during this study and significant of the study. Chapter 2 describes a comprehensive literature on EDM system including the development of power supplies. This chapter also include literature on Metal-on-Metal hip replacement detailed on lubrication and surface texturing on hip implant. Chapter 3 explains the research methodology including the mathematical equation used for simulation of power supply. This chapter also describes the experimental setup for machining micro-dimples on hip implant and tribology experiments to analyze friction on hip implant. Chapter 4 presents the simulation of Flyback converter and control design. Chapter 5 discusses the results obtained from machining micro-dimples on metallic acetabular cup in term of gap voltage and gap current profile, surface images and MRR. This chapter also includes the experimental results obtained from friction test, comparison between non-dimpled and micro-dimpled hip implant. Chapter 6 concludes the study and gives suggestion for further work.

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